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SHORT COMMUNICATION

A FIELD EXPERIMENT OF CUSP FORMATION ON A COARSE CLASTIC BEACH USING A SUSPENDED VIDEO-CAMERA SYSTEM

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ABSTRACT

Cusp formation was continuously monitored on a manually flattened, plane section of a coarse clastic, microtidal, pocket beach on the Pacific coast of Japan using a CCD camera suspended in the air. Vertical video pictures enabled the examination of the temporal change in foreshore morphologies and swash pattern. Boulders on the beach face appeared to have triggered the formation of beach cusps, which gradually and successively grew up alongshore. In 2·5 h, two well defined beach cusps had developed with a spacing of 2·2 and 2·5 m, respectively. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: beach cusps; coarse clastic beach; video-camera system; field experiment

INTRODUCTION

Beach cusps are regularly spaced, rhythmic cuspidate micromorphologies formed in the foreshore zone of sandy or gravel beaches. More than a century and a half has passed since Palmer (1834) first observed how the process of sediment movement leads to the development of beach cusps. Various ideas, hypotheses and models on the origin, formation or development of beach cusps have been presented and a large body of literature has accumulated: see Trenhaile (1997, pp. 91–93) and Komar (1998, pp. 456–470) for reviews. There have been many studies in recent years (Allen *et al.*, 1996; Holland and Holman, 1996; Masselink *et al.*, 1997; Masselink and Pattiaratch, 1998; Coco *et al.*, 1999; Masselink, 1999), most of them dealing with the problem of discrimination of the edge wave model proposed by Guza and Inman (1975) and the self-organization model of Werner and Fink (1993).

Most beach cusp research has been conducted on cusp morphologies that have already formed. The present study attempted to examine the formation of beach cusps from a manually flattened, plane beach, focusing on the temporal change in morphology and swash pattern. A suspended video-camera system was used to record the change.

THE SUSPENDED VIDEO-CAMERA SYSTEM

The system comprises: (1) a light-weight CCD colour camera module (model: SONY XC-777; weight: 75 g) with a wide-angle lens; and (2) a small video-tape recorder (VTR) with a 4-inch LCD monitor (model: SONY GV-SX50; weight: 980 g). Both components are driven by batteries. The camera module, contained in a capsule made of Styrofoam, is suspended in the air from the top of a carbon-fibre pole erected at a high angle (Figure 1). The camera is connected by a coaxial cable to the VTR placed on the ground. The appropriate camera position can be fixed by looking at images on a monitor screen of the VTR, and the camera capsule is

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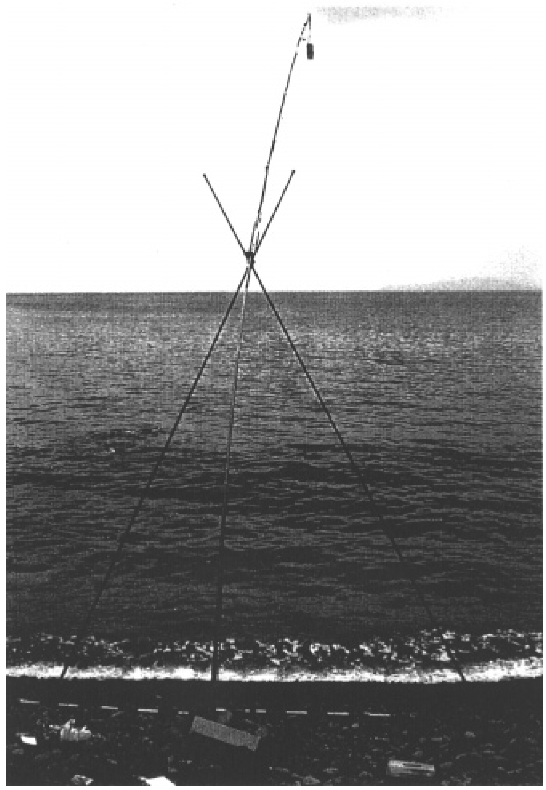

Figure 1. A CCD camera module suspended at a height of 8·5 m from the top of a pole. The coverage of video images was 11 m × 7 m.

anchored by two nylon strings to stabilize it. The VTR is operated at a normal speed of 30 frames 1 per second. The recording system is portable and easy to set up.

STUDY SITE AND EXPERIMENT

A coarse, clastic, microtidal beach located at the head of a cove near the tip of Cape Manazuru in Sagami Bay, Japan, facing the Pacific Ocean, was selected as a study site. The beach has a slightly arched, east–west oriented shoreline 160 m long. The cape is formed from andesitic rocks, and all the beach material is of andesite origin. The foreshore beach is composed of rounded pebbles with approximate diameters of 4 cm (b-axis) and the upper part of the beach (higher than about 2 m above sea level) is composed of large cobbles more than 10 cm in diameter. Some boulders rest on the beach. The depth of coarse clastic cover on the andesitic bedrock decreases from a cliff behind the beach towards the shoreline, and the bedrock is exposed in the shallow water region. Part of the bedrock is exposed in a limited area in the foreshore zone of the eastern portion of the beach.

A test of the suspended camera system was made on 14 March 1995 at the experiment site in the central portion of the beach. At this time beach cusps with a spacing of about 4 m and an indentation of 2 m developed in the foreshore zone with an alongshore length of about 15 m in the central portion of the beach including the experiment site.

The following morning, 15 March, all pre-existing beach cusps were manually destroyed during low tide to make a plane beach (manpower of seven students was needed to complete this work). Mean slope angle of the beach was 12·4°. The camera was installed 8·5 m above mean sea level (MSL), and the coverage of the video

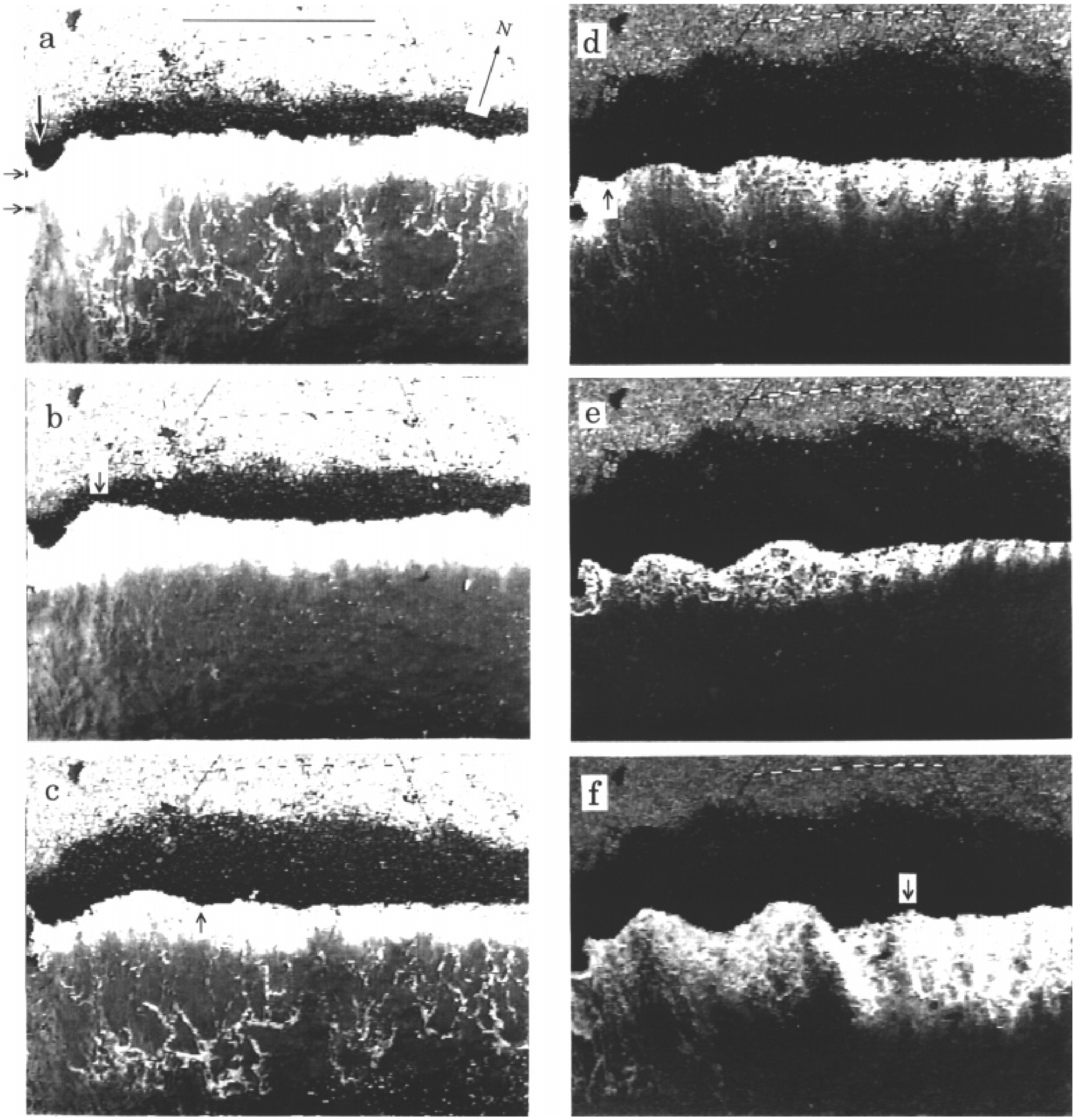

Figure 2. Wave runup limit at different times. (a) 14:50, immediately after the beginning of experiment. The beach is almost planar except at the western end where three boulders (arrowed) are located. The bar is 4 m long. (b) 15:05, a depression formed adjacent to the largest boulder. (c) 15:17, incipient beach cusps. (d) 16:36, two growing beach cusps. (e) 16:50, the beach cusps with increasing curvature. (f) 17:30, well developed beach cusps

images was approximately 11 m in alongshore distance and 7 m in on–offshore extent. The experiment started at 14:50, when it was nearly at high tide (50 cm above MSL). During the experiment the beach experienced an ebb tide with a gradual drop of sea level of about 30 cm. Waves, instrumentally measured off Hiratsuka (25 km northeast of the study site), had a significant height of 0·4 m and period of 6 s. Incident waves broke close to the shoreline in the mode of surging or plunging. Rough measurements of breaking waves using a surveyor's rod indicated that they were 0·5 m high on average during the experiment. Most waves approached normal to the shore.

RESULTS AND DISCUSSION

Figure 2a–f are a series of video images showing the pattern of wave uprush limit at different times. The uprush limit pattern reflects the beach-face configuration well. Figure 2a is an image obtained at 14:50, immediately after the experiment started, showing that the beach face was almost planar except at the western (towards the left in the figure) end of the experiment site where three boulders (arrowed) were present; the largest boulder (80 cm in diameter) was located in the upper part of the swash zone (bold arrow), and the other two were slightly visible above the water. Figure 2b, an image taken at 15:05, indicates that a topographic depression (arrow) formed next to the area of the boulders. At 15:17 (Figure 2c) the depression became a cusp embayment with a cusp horn (arrow) forming to the east, and at 16:36 (Figure 2d) sediment accumulation occurred in front of the largest boulder yielding a new cusp horn (arrow), and two beach cusps are clearly visible. At 16:50 (Figure 2e) the two beach cusps showed increasing curvature and had migrated slightly eastwards (about 0·3 m). The two cusps had developed further with more notable indentation by 17:30 (Figure 2f). At this stage the cusp spacing, λ, and indentation, δ, were measured in the field using a tape measure: the western cusp had $\lambda = 2{\cdot}2$ m and $\delta = 1{\cdot}5$ m and the eastern cusp had $\lambda = 2{\cdot}5$ m and $\delta = 1{\cdot}5$ m. Figure 2f shows that a new depression (arrow) had begun to develop. Unfortunately the nightfall prevented us from recording further cusp development, so the experiment ceased at 17:35. Visual observation around 18:00 showed that the new depression increased the degree of indentation, which resulted in the development of a new beach cusp with a similar λ-value to those of the former two cusps but with a smaller δ-value. Beach cusp development was observed only within the experiment site.

During the experiment, erosion occurred in the cusp embayment, so that the bedrock there became partly exposed as sea level was receding. The cusp horn protruded due to accretion. Many previous studies have described cusp formation as purely due to accretionary processes with the horns experiencing more sediment accumulation than the embayment (e.g. Russell and McIntire, 1965; Sallenger, 1979; Takeda and Sunamura, 1983; Antia, 1987; Sato *et al.*, 1992; Masselink *et al.*, 1997); some have reported that they form due to erosional processes with the horns being residual features that experienced less erosion than the embayment (Smith and Dolan, 1960; Miller *et al.*, 1989); and others have stated that they are the result of a combination of accretionary and erosional processes, occurring respectively at the horn and in the embayment (e.g. Kuenen, 1948; Otvos, 1964; Guza and Inman, 1975) as shown in the present experiment. Occurrence of the three cusp-formative modes seems to depend on whether the pre-existing beach-face slope is gentler or steeper compared with the slope that is necessary for input waves to generate beach cusps and continue their development.

Video pictures show that wave uprush during cusp formation occurs simultaneously between adjacent cusp embayments; and the uprush flow deflected by the cusp horn meets in the central portion of the embayment and recedes, enhancing the backwash flow, which results in retardation of the uprush of the next wave. This flow pattern, called 'horn-divergent flow' by Masselink and Pattiaratch (1998), is similar to the one already reported (e.g. Bagnold, 1940; Dean and Maurmeyer, 1980; Masselink *et al.*, 1997), and is typical of steep, reflective beaches (Dyer, 1986, p. 300).

In Werner and Fink's (1993) simulation study, the presence of incipient topographic depression on the beach face is assumed for cusp formation, and is comparable with descriptions in early studies by Johnson (1910), Kuenen (1948) and Russell and McIntire (1965). A depression that appeared near the western end of the experiment site (Figure 2b) was probably caused by the presence of the adjacent boulders. The depression would perturb swash pattern to accelerate backwash flow, thereby causing erosion, which results in a cusp

embayment. Uprush flow over topographic highs (relative to the embayment) at both sides of the embayment decelerates and deposits sediment, eventually giving rise to the occurrence of cusp horns; this in turn would disturb the pattern of swash flow on a contiguous, still planar beach face, enhancing backwash flow, which leads to the formation of a new cusp embayment. Thus, the interaction between topography and flow structure in the swash zone moves alongshore producing beach cusps.

CONCLUDING REMARKS

A suspended video-camera system was found to be useful to continuously monitor beach cusp formation. A series of vertical video pictures displayed the development of cusps on the experimental beach. Beach cusps started as a topographic depression adjacent to boulders on the beach face. A protrusion such as boulders could disturb the uniformity of flow structure in the swash zone, resulting in cusp generation. The interaction between cusp morphologies and the flow structure developed alongshore yielding a succession of beach cusps, with their horns experiencing accretion and the embayments being eroded.

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